CHAPTER 4

ELECTRICAL UNITS

Chapter 3 explained how the base units of mass, length and time were used to build up coherent expressions for solving mechanical problems. In this Chapter, the base SI unit, the ampere, will be used to give the student an understanding of a simple electrical circuit. From this, equations will be evolved to the stage reached in the previous chapter (power) and in later chapters it will be shown that there is a common relationship between all types of power.

4.1 THE AMPERE

In Chapter 1 it was stated that electric current would be regarded as a movement of electrons. There are two types of electric current -

(i) Direct current, in future referred to as d.c. This is the type of current drawn from a car battery.

(ii) Alternating current, which will be abbreviated to a.c. This is the type of current normally used in a house or factory.

The principles of direct current are not as involved as those of alternating current, so this type of current will be studied first.

The electrostatic charge on an electron is so small that it requires 6.24×10^{18} electrons to make one coulomb (C), the name of the SI unit of charge. The number of electrons passing through an imaginary plane, which cuts an electron flow at right angles is called the total charge (Q). Current (I) is the rate of flow of charge in coulombs per second. The unit for current is the ampere (A) and the equation for determining the current is given by dividing the total charge, in coulombs, by the time, in seconds, that this charge exists.

$$\text{Current} = \frac{\text{total charge}}{\text{time}}$$

$$I = \frac{Q}{t} \text{ amperes}$$

Example 4.1

Determine the current in a conductor if 240 coulombs of electric charge pass a given point in that conductor in one minute.

$Q = 240$ C

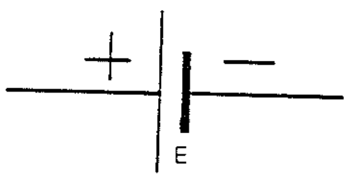
$t = (1 \times 60) = 60$ s

$I = ?$ A

$$I = \frac{Q}{t} = \frac{240}{60} \text{ amperes} = 4 \text{ A.}$$

Electrons move at random in conducting materials. A given piece of material will always contain the same number of electrons. Electrons moving along or out of a material in the one direction must be replaced to keep the total number of electrons in that material constant. A source of electrons must be available before unidirectional electron movement (current) can occur. This source has to be joined to the material so that any electrons leaving the material are immediately replaced by electrons from the source. The most frequently used source of electrons is called an electromotive force, this word being abbreviated to e.m.f. and the source being designated by the capital letter 'E'. The unit of e.m.f. is the volt (V). The symbol for a simple e.m.f. source is shown in Figure 4.1.

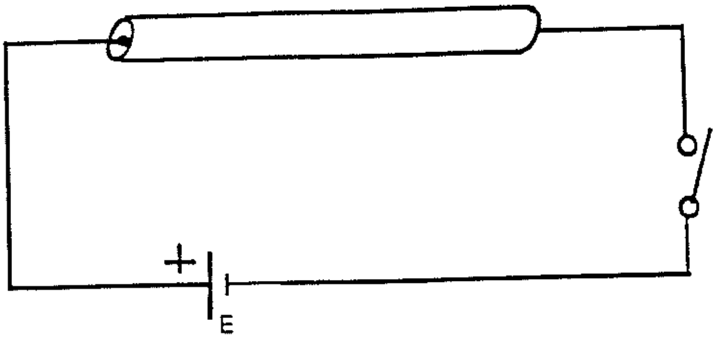
Figure 4.1



The negative side of the source is said to have a reference value of zero volts, even the section that supplies the electrons. The positive side has a reference value above zero volts . gives it a plus value of volts.

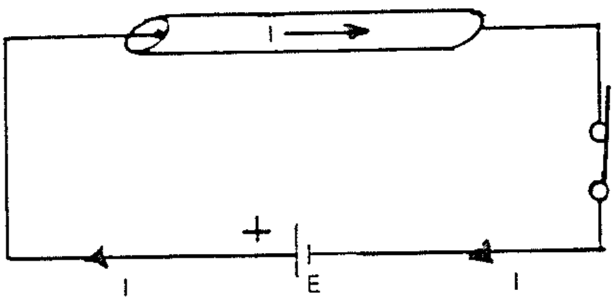
The source is connected to the conductor as shown in Figure 4.2.

Figure 4.2

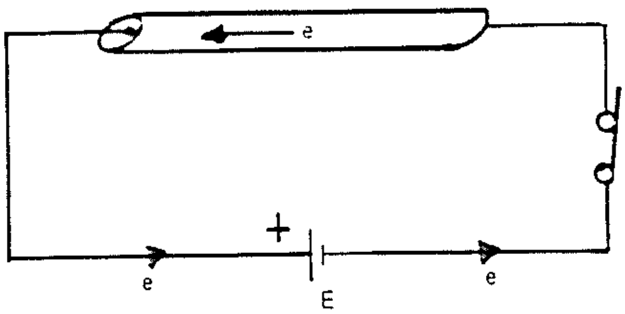


4.2 ELECTRON AND CURRENT FLOW

When electricity was first discovered it was assumed that electrons moved from a point of high voltage to a point of lower voltage. As electrons were considered to be electric current it was said that current flowed from the positive connection of the source to the negative connection of the source outside the source itself. However, at a much later date this was found to be incorrect. The problems involved in reversing the generally accepted principle of electron flow proved so difficult that it was decided to state that conventional current flowed from positive to negative outside a source, while electron flow was negative to positive outside the source.



Conventional current flow (fig. 4.3)



Electron flow (fig. 4.4)

4.3 OPPOSITION TO CURRENT FLOW

Electrons under the influence of an e.m.f. shift from atom to atom as they move through a material. The ease with which they move depends on many factors, the existance of these factors depending on whether a circuit is supplied from an a.c. or d.c. source. The total opposition to current flow is called the impedance of the circuit (symbol Z) and the unit of impedance is the ohm (symbol Ω). The impedance of a.c. circuits will be discussed in later chapters. The only opposition by a circuit to a constant d.c. current is called the resistance (R) of the circuit. As it is opposition to current, resistance has the same units as impedance, namely, the ohm.

4.4 OHM'S LAW

Ohm's Law implies that, provided all resistance factors remain constant the current in a conductor is directly proportional to the e.m.f. applied to the conductor and inversely proportional to the resistance of that conductor. Mathematically it states that :

$$I = \frac{E}{R}$$

This means that if the resistance remains constant and the applied e.m.f. is increased, the current in the conductor increases. Conversely if the e.m.f. across the conductor remains constant and the resistance of the conductor is increased, the current in the conductor decreases.

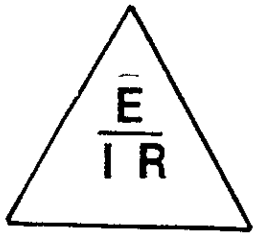
The equation for Ohm's Law may be transposed to find the resistance or applied e.m.f. of a circuit.

$$I = \frac{E}{R} \text{ amperes}$$

$$E = I.R. \text{ volts}$$

$$R = \frac{E}{I} \text{ ohms}$$

A simple method of remembering the correct equation when applying Ohm's Law is by the use of the Ohm's Law triangle.

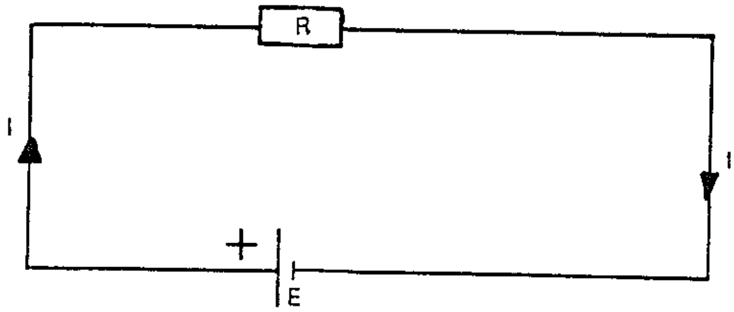


Ohm's Law triangle

If the unknown quantity is covered the method of calculating the unknown quantity is revealed

Figure 4.5 shows a simple circuit using the Ohm's Law symbols.

Figure 4.5



<u>Example 4.2</u>

An e.m.f. of 200 volts d.c. is applied to a circuit which has a resistance of 20 ohms. Determine the current in the resistor.

$E = 200\ V$

$R = 20\ \Omega$

$I = ?\ A$

$$I = \frac{E}{R}$$

$$= \frac{200}{20} \text{ amperes}$$

$$= 10\ A.$$

<u>Example 4.3</u>

A current of 20 amperes flows in a resistor of 5 ohms. Determine the value of e.m.f. applied to the resistor.

$I = 20\ A$

$R = 5\ \Omega$

$E = ?\ V$

$$E = IR$$

$$= (20 \times 5) \text{ volts}$$

$$= 100\ V$$

Example 4.4

An e.m.f. of 240 volts d.c. applied to a resistor causes a current of 12 amp resistor. Determine the resistance of the resistor.

$E = 240\ V$

$I = 12\ A$

$R = ?\ \Omega$

$$R = \frac{E}{I} = \frac{240}{12}\ \text{ohms} = 20\ \Omega$$

4.5 ELECTRICAL POWER

Base units of mass, length, time and current may be used to show that electrical power is the product of the applied e.m.f. of a circuit and the current in that circuit. Using base units —

$$E = kg\ m^2\ s^{-3}\ A^{-1}$$

$$I = A^{+1}$$

$$P = E\ I = kg\ m^2\ s^{-3}\ A^{-1}\ A^{+1} = kg\ m^2\ s^{-3}$$

This is the same coherent unit used for mechanical power, so the unit for electrical power must be the watt (W). If the Ohm's Law equation for voltage, $E = I\ R$, is substituted in the power equation, the power equation becomes —

$$P = (I\ R)\ I = I^2\ R \text{ watts}$$

Similarly, if $I = \frac{E}{R}$ is substituted in the power equation, it becomes —

$$P = E\left(\frac{E}{R}\right) = \frac{E^2}{R} \text{ watts}$$

From this, it can be seen that provided two of the parameters of the Ohm's Law equation are known, power may be determined.

Example 4.5

A current of 20 amperes is produced when a e.m.f. of 200 volts d.c. is applied to a circuit. Calculate the power absorbed by the circuit.

$E = 200\ V$

$I = 20\ A$

$P = ?\ W$

$$P = E\ I = (200 \times 20) \text{ watts} = 4000\ W = 4\ kW$$

Example 4.6

Determine the power absorbed by a 10 ohm resistor which carries a current of 20 amperes.

$R = 10\ \Omega$

$I = 20\ A$

$P = ?\ W$

$$P = I^2 R = (20 \times 20 \times 10) \text{ watts} = 4000\ W = 4\ kW$$

Example 4.7

Determine the power consumed by a 10 ohm resistor, if it is connected to a 200 volt d.c. supply.

E = 200 V

R = 10 Ω

P = ? W

$$P = \frac{E^2}{R}$$

$$= \frac{200 \times 200}{10} \text{ watts}$$

$$= 4000 \text{ W}$$

$$= 4 \text{ kW}$$

4.6 MEASUREMENTS OF ELECTRICAL UNITS

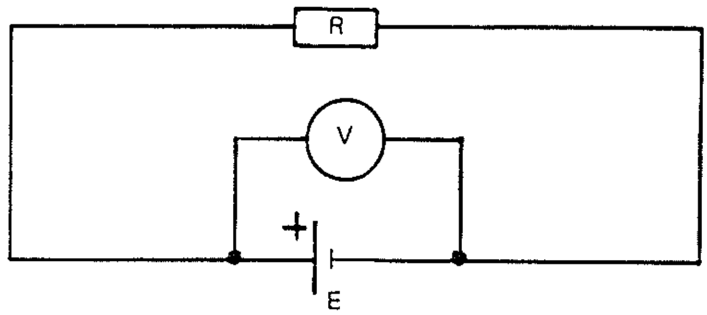
The only function of a meter is to record or show a particular measurement at a given time. Meters consume power which is regarded as waste power so it is desirable that meters keep their power consumption to a minimum. The connection of meters to a circuit should cause a small as possible change to existing voltages and currents within that circuit.

Meters used to measure e.m.f., current and power are the voltmeter, ammeter and wattmeter respectively.

(a) The Voltmeter

The e.m.f. of a source is often referred to as the electrical pressure of the source. The source e.m.f. exists whether the source is being used or not. The voltmeter is used to measure this electrical pressure. The electrical pressure in a source may be likened to the pressure in a water main. The water in the main is always available even though it is not always being utilised. To measure the pressure at the source, the voltmeter must be connected across the source terminals. (Figure 4.6).

Figure 4.6



The resistance of the voltmeter must be very high so that minimum current passes through the meter. Excessive current through the meter would consume too much power from the source.

(b) The Ammeter

If it was necessary to measure the amount of water moving through a pipe, a gauge would have to be inserted in that pipe so that all the water went through the gauge. Similarly, to measure the electrons moving in a circuit, a meter must be inserted in such a position that all the electrons moving in that part of the circuit pass through the meter. As electrons are current and current is measured in amperes, a meter which fulfills the above requirements is called an ammeter and is connected in the circuit as shown in Figure 4.7.

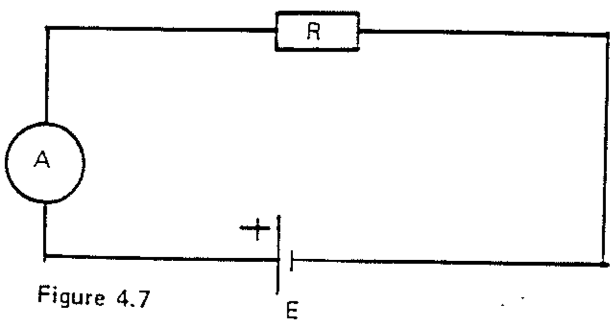


Figure 4.7

The resistance of the ammeter must be as low as possible so that the movement of electrons throughout the circuit is not hindered.

(c) The Wattmeter

Power is the product of electromotive force and current. For a meter to read this product direct it must contain a means of measuring the e.m.f. and the current, or a combination of the voltmeter and ammeter readings. The most common wattmeter in use is the electrodynometer type of wattmeter. It has a current coil which measures the electron flow and is connected to the main part of the circuit, and a coil similar to that of a voltmeter which is connected across the applied e.m.f. (Figure 4.8).

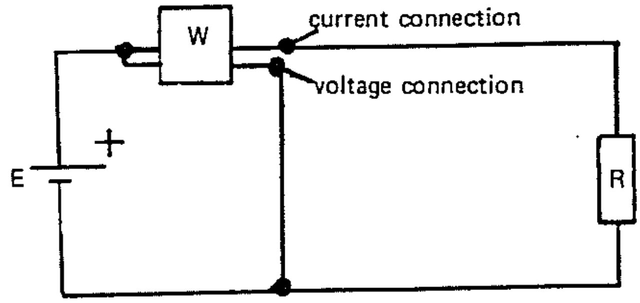


Figure 4.8

The wattmeter records directly the resultant reaction between the currents flowing in these two coils.

(d) Voltmeter, ammeter and wattmeter in the same circuit

If the three meters are to be used in the same circuit the ammeter and the current coil of the wattmeter, must be connected into the circuit so that the electrons pass through both of them. The voltmeter and the coil in the wattmeter that measure the e.m.f. (referred to as the potential coil) are connected across the e.m.f. source. (Figure 4.9).

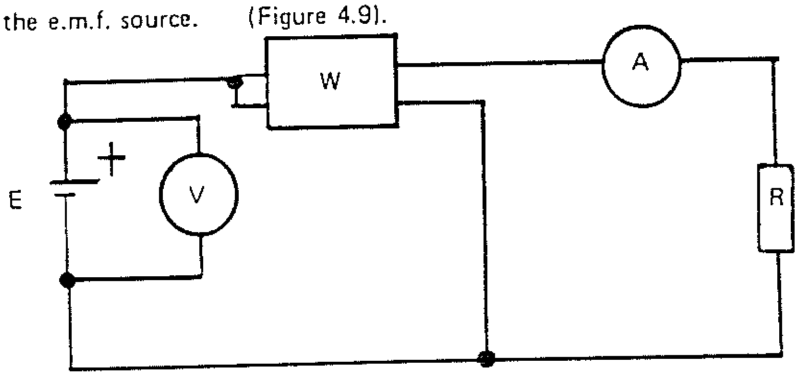


Figure 4.9

The ammeter and the current coil of the wattmeter are said to be connected in series while the voltmeter and the potential coil of the wattmeter are said to be connected in parallel.

Equations in chapter

(1) $I = \frac{Q}{t}$

(2) $I = \frac{E}{R}$

(3) $E = I\ R$

(4) $R = \frac{E}{I}$

(5) $P = E\ I$

(6) $P = I^2R$

(7) $P = \frac{E^2}{R}$

TUTORIAL 1.4

(i) A resistance of 120 ohms is connected to a 240 volt d.c. supply. Calculate the current drawn from the supply.

(ii) A purely resistive circuit draws 5 amperes from a 12 volt source. Calculate the resistance of the circuit.

(iii) Calculate the voltage that will cause 2.5 amperes of current to flow in a 10 ohm resistor.

(iv) Determine the power consumed when 3 amperes of current passes through a 5 ohm resistor.

(v) A resistive circuit draws 15 amperes from a 240 volt source. Calculate the power consumed by the resistor.

(vi) A 40 ohms resistor is connected to a 240 volt d.c. supply. Calculate the power consumed by the resistor.